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INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 4 :
B23K 31/02, F16L 13/06
B23K 9/235, C21D 9/50

A1

(11) International Publication Number: WO 88/ 06505

(43) International Publication Date: 7 September 1988 (07.09.88)

(21) International Application Number: PCT/GB88/00136

(22) International Filing Date: 26 February 1988 (26.02.88)

(31) Priority Application Number: 87100959

(32) Priority Date: 28 February 1987 (28.02.87)

(33) Priority Country: CN

(71) Applicants *(for all designated States except US)*: BEIJING AERONAUTICAL MANUFACTURING TECHNOLOGY RESEARCH INSTITUTE [CN/CN]; P.O. Box 863, Beijing (CN). THE WELDING INSTITUTE [GB/GB]; Abington Hall, Abginton, Cambridge CB1 6AL (GB).

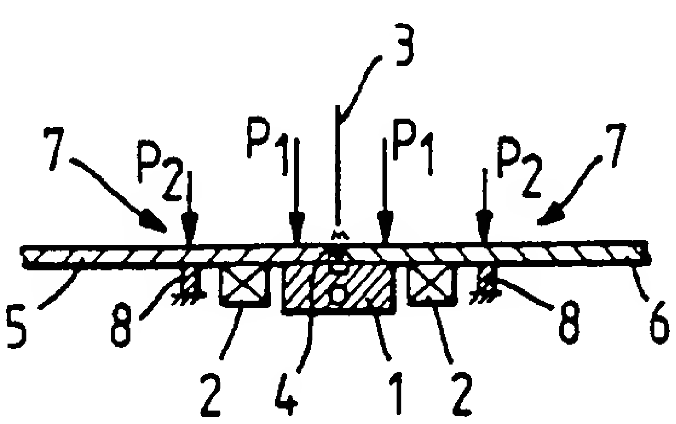
(72) Inventors; and
(75) Inventors/Applicants *(for US only)* : GUAN, Qiao [CN/CN]; P.O. Box 863, Beijing (CN). BROWN, Kenneth, William [GB/GB]; 61 Panton Street, Cambridge CB2 1HL (GB). GUO, Delun [CN/CN]; CAO, Yang [CN/CN]; LI, Congquin [CN/CN]; SHAO, Yichen [CN/CN]; LIU, Jida [CN/CN]; P.O. Box 863, Beijing (CN).

(74) Agent: SKONE JAMES, Robert, Edmund; Gill Jennings & Every, 53/64 Chancery Lane, London WC2A 1HN (GB).

(81) Designated States: AT (European patent), BE (European patent), CH (European patent), DE (European patent), DK, FR (European patent), GB (European patent), IT (European patent), JP, LU (European patent), NL (European patent), SE (European patent), US.

Published
With international search report.
Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.

(54) Title: IMPROVEMENTS RELATING TO WELDING



(57) Abstract

A method and apparatus for low stress and non-distorsion welding a weld zone defined by one or more thin walled workpieces (5, 6). A temperature profile is generated across an area including the weld zone, the temperature profile comprising in sequence a first zone (9) including the weld zone, a second zone (10) adjacent the first zone and having a temperature higher than the first zone, and a third zone (11) adjacent the second zone and having a temperature lower than the second zone. A weld operation is performed on the weld zone while the temperature profile exists and while restraining transient out-of-plane buckling movement of the workpiece or workpieces.

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Improvements Relating to Welding

The invention relates to methods and apparatus for welding a weld zone defined by one or more workpieces and in particular to in-process controlling welding stresses and distortions during welding of thin-walled structural elements.

Buckling distortions which always take place in the welding of thin-walled structures are mainly caused by residual compressive plastic strains and residual stresses as a result of local non-uniform heating during welding. Usually, two categories of methods could be adopted to eliminate welding distortions in thin-walled structures: methods applied before welding - e.g. pre-deformation etc, hereby the welding distortions are compensated by a counter-deformation formed in the structural elements prior to welding; methods applied after welding - once welding distortions are in existence, they are removed or eliminated afterwards by special flattening processes. These methods applied either prior to welding or afterwards should be arranged as a special working operation in the manufacturing procedure, and both of them need special installations, resulting in increasing cost and uncertain qualities of welded structures.

The pre-tensile loading could be classified in the category of methods applied before and during welding for controlling welding stresses and distortions in thin-walled structures. In this case, for each particular structure of panels with stringer, a specially designed installation for tensile loading is required.

Owing to the complexity, reduced efficiency and reduced flexibility in practical execution, applications of these methods are limited.

A method described in JP-A-6018292 could be mentioned as an example of a method applied after welding for reduction of welding residual stresses and distortions. Methods in this category are based on creating an appropriate temperature gradient after the welding of thick plates, by cooling the weld zone and heating both side zones adjacent to the weld.

Another method described in SU-A-1066765 could be classified as a method applied during welding for controlling stresses and distortions. Using the thermal absorbing effect of volatile materials, intensively reducing the temperature in both side zones adjacent to weld, the welding stresses and distortions could be reduced.

JP-A-5311138 describes a method for controlling distortions during welding of panels with reinforced ribs in which a huge specially designed installation with heating and flattening base plates is applied for each particular construction of panels.

The tensile stresses induced in specimens by a preset temperature gradient as a result of cooling the weld zone and heating side zones close to the weld for controlling stresses and distortions during welding are discussed by Soviet authors Y.I. Burak et al in papers presented in "Automatic Welding" No. 3, 1977 and No. 5, 1979. The authors recommended an approximate calculation for thin plates but experiments were carried out only on specimens with thicknesses of 4mm and above. No further reports are available on experiments with thicknesses less than 4mm, nor on an application of this method in practice. It has been identified by experiments that this method could not be as effective as expected for

thin-walled elements especially with thicknesses less than 4mm in which the problem of buckling distortions are significant; and it has also been proved by the results of repeated experiments that the required preset tensile stresses in the joint area of workpieces to be welded ceases to exist when transient buckling distortion occurs in areas with compressive stresses as a result of the superposition of the preset temperature distribution and the welding temperature distribution.

In accordance with one aspect of the present invention, a method of welding a weld zone defined by one or more workpieces comprises creating a temperature profile across an area including the weld zone, the temperature profile comprising in sequence a first zone including the weld zone, a second zone adjacent the first zone and having a temperature higher than the first zone, and a third zone adjacent the second zone and having temperature lower than the second zone; and performing the weld operation on the weld zone while the temperature profile exists and while restraining buckling movement of the workpiece or workpieces.

In accordance with a second aspect of the present invention, apparatus for welding a weld zone defined by one or more workpieces comprises temperature profile generating means for creating a temperature profile across an area of the workpiece or workpieces including the weld zone, the temperature profile comprising in sequence a first zone within which the weld zone is positioned in use, a second zone adjacent the first zone and having a temperature higher than the first zone, and a third zone adjacent the second zone and having a temperature lower than the second zone; and welding means for performing a weld operation on the weld zone while the temperature profile exists across the area, the arrangement being such that during a weld operation

buckling movement of the workpiece or workpieces is restrained.

This invention deals with the distortion troubles and overcomes the shortcomings in existing methods for controlling welding stresses and distortions which have been described. This invention is aimed at providing a method and relevant apparatus for controlling welding stresses and distortions, executable directly in-process of the welding of thin-walled structural elements with thicknesses especially less than 4mm in which the buckling distortions are substantial; for industrial application, this method and apparatus must be simple in operation and manipulation, economical in energy consumption and not necessitating great investment in large special-purpose installations. By means of this method and apparatus, practical low stress and non-distortion LSND welding results are expected to be achieved. Undoubtedly, it will also be suitable for welding of thin-walled structural elements of thickness above 4mm.

The specific and essential feature of this invention is to provide the required stretching effect during welding by means of preventing the workpieces to be welded from transient out-of-plane buckling distortions which always take place as a result of superposition of the preset heating and welding heat source itself. The stretching effect is herein defined as the tensile stress distribution in the weld joint zone induced by a local preset heating temperature distribution. The higher the level of tensile stress, the better the results of controlling the welding stresses and distortions. The preset tensile stresses in the weld joint zone are formed due to contraction by cooling the first and the third zones and expansion by heating the second zone - both side zones adjacent to the weld. If out-of-plane

buckling distortions take place during heating and welding, the stretching effect will no longer be effective, and it will have an adverse influence on the results of controlling welding stresses and distortions.

Preferably, the first, second and third zones of the temperature profiles are duplicated on each side of the weld zone. In other words, a composite first zone will be generated extending on each side of the weld zone.

In thin-walled structural elements to be welded, transient buckling distortions normally occur under the compressive stresses caused by preset heating and welding. Based on the theory of plates and shells, analyses of welded structures indicate that plates with thicknesses above 4mm are possessed of higher critical compressive stresses at which buckling occurs; therefore structural elements of thicknesses above 4mm are less sensitive to levels of compressive stresses with respect to buckling. But in the case of plates of thicknesses less than 4mm, which have lower critical compressive stresses at which buckling occurs, structural elements are more sensitive to changes in levels of compressive stresses during local preset heating as well as welding. Buckling distortions will take place in the workpieces while welding heating is superposed on the local preset heating.

In one application of the invention, the workpieces are held stationary during the welding operation and in this case, the restraining step is preferably performed by restraining means at both the weld zone and the third zones, the restraining means applying flattening forces.

With this technique the distortions previously experienced in thin-walled structural elements can be made insignificant, providing the required quality of welded elements. It is simple in operation and saves cost.

Typically, the restraining step also includes the step of applying a force to the workpiece or workpieces adjacent the weld zone.

In this case the restraining means may comprise at least one load member having a pair of fingers, one of which contacts a workpiece in the weld zone and the other of which restrains the workpiece in the third zone.

In one example of apparatus for the stationary welding case, three firm backup supporting bars parallel to the weld are applied under the structural elements to be welded. One of them is located in the centre right under the weld. The other two supporting bars are symmetrically located on both sides of the central backup bar; the central backup bar has a groove to accomodate an interchangeable backing insert in which channels are provided respectively for inert gas supply to the underside of the weld as well as for circulation of a cooling medium; on both sides symmetrically to the weld the two cavities between central backup bar and side backup bars contain heaters; two opposing rows of loading mechanisms are applied on both sides of the weld for application of flattening forces to the upperside of the workpieces; each loading mechanism has a hinged double finger clamping holding the workpieces firmly against both the central and the side backup bars. Operation with this facility is simple. It is possessed of a satisfactory flexibility in execution to fulfil various manufacturing requirements and provides stability and reliability in engineering applications. In this stationary welding case, the action of the restraining means at both the weld zone and the third zones has the following effects:

a. The prevention of transient out-of-plane buckling;

b. The improvement of conduction heat-sinking with the third, cool zone; and,

c. The increase in frictional resistance to in-plane sheet rotating movement.

The points on each side of the weld zone at which flattening forces are to be applied are selected such that the first point is as close to the line of the weld as practicable while the second point is within the third zone but as close as practicable to the second zone. The values of the flattening forces necessary to prevent the structural elements from transient buckling are determined by the specific characteristics of the material used and the structure to be welded.

The invention may be applied to a variety of different weld situations but is primarily of use for the butt welding of plates as well as longitudinal butt welding of cylindrical or conical shells. In addition, the invention can be used for straight fillet and Tee type welds for panels with ribs. In this case, in order to create the local preset heating temperature profile, the weld zone is cooled and both sides adjacent to the weld are heated on the flat panel, as well as on the appropriate areas of the vertical ribs, while preventing both the flat panel and the ribs from transient out of plane buckling.

A second type of welding operation involves relative movement between the workpiece and restraining means during the welding operation. In particular, and in accordance with a third aspect of the present invention, a method of continuously welding an elongate weld zone defined by one or more workpieces comprises creating a temperature profile across an area including the weld zone, the temperature profile comprising in sequence a first zone including part of the weld zone, a second zone adjacent the first zone and having a temperature higher than the first zone, and a third zone adjacent the second zone and having a temperature lower than the second zone,

the temperature profile being created at a position upstream of a welding position; causing relative movement between the said part of the weld zone and the welding position; and performing a weld operation on the said part of the weld zone at the welding position while the temperature profile exists across the part of the weld zone and while restraining buckling movement of the workpiece or workpieces.

In this case, the restraining means cannot apply flattening forces on to the workpiece or workpieces since movement of the workpiece or workpieces relative to the restraining means must be permitted. Instead, the restraining means preferably includes first means positioned adjacent the workpiece or workpieces in use and spaced from the weld zone, preferably in the third zone of the temperature profile, to restrain movement of the workpiece or workpieces towards the restraining means.

Where the weld zone is defined by more than one workpiece, it may also be necessary to provide additional restraining means, for example tack welds or the first pass of a multi-pass weld.

Typically, in either case, the restraining means includes one or more support members on which the workpiece or workpieces rest.

The first and third zones of the temperature profile effectively define heat sinks and conveniently these zones are coupled together for ease of cooling.

Typically, the temperature profile will be substantially symmetrical about the weld zone.

Conveniently, the temperature profile generating means comprises first cooling means for cooling the first zone, heating means for maintaining the second zone at a temperature higher than the first zone, and second cooling means for cooling the third zone.

In one application of the invention, the weld zone may be defined by a pair of butted tubular workpieces. In this case, the restraining effect is provided inherently by the adequate stiffness of the workpieces themselves and no additional restraining means is required.

Some examples of methods and apparatus according to the present invention will now be described and contrasted with known methods and apparatus with reference to the accompanying drawings in which:-

Figure 1, is a diagrammatic view showing one example of a LSND welding method for longitudinal butt welding of plane elements;

Figure 2, is a diagrammatic view of LSND welding of fillet weld joints;

Figure 3, is a diagrammatic view of LSND welding of Tee type weld joints;

Figure 4, illustrates graphically temperature distribution by local preset cooling and heating, and relevant thermal stress distribution;

Figure 5, is a schematic view showing the transient out-of-plane buckling distortions under compressive stresses while conventional one-point loading is applied;

Figure 6, is a schematic view showing the flattening effect with two-point loading to prevent the workpieces from transient out-of-plane buckling;

Figure 7, illustrates the curves of temperature distributions with preheating, and local preset cooling and heating temperature distribution in case of hardenable materials to be welded;

Figure 8, is a diagram showing the experimental measurement results of residual compressive plastic strains after conventional welding and LSND welding, respectively;

Figure 9, is a diagram showing the experimental measurement of longitudinal residual stress distributions in a cross-section of the workpiece after conventional welding and LSND welding respectively;

Figure 10, illustrates graphically the comparison of residual stress distributions after conventional welding and welding using a method with higher T_{max} according to the invention;

Figure 11, is a histogram comparing the deflection after conventional welding with examples welded according to the invention;

Figure 12, is a part sectional view of loading, cooling and heating systems of one example of apparatus according to the invention for longitudinal butt welding of plates;

Figure 13, is a part sectional view of loading, cooling and heating systems of a second example of apparatus according to the invention for longitudinal welding of cylindrical or conical shells;

Figure 14, is a part sectional view of a third example of apparatus according to the invention for continuous welding plates as they move under a welding head;

Figure 15 comprises a pair of half sections taken on the lines A - A, B - B in Figure 14;

Figure 16, is a side elevation of the Figure 14 apparatus;

Figure 17, is a partly cut-away view of two cylinders being welded;

Figure 18, is a side elevation of apparatus for continuously welding a pair of cylinders; and,

Figure 19, is an end elevation of the Figure 18 apparatus.

Fig. 1 illustrates the case of a low stress and non-distortion (LSND) welding method for a longitudinal

butt joint 4 between a pair of metal sheets 5, 6. Weld zone heat is extracted by a cooling system 1, while both side zones adjacent to weld zone are heated by a heating system 2; in this figure the welding heat source 3 is illustrated schematically. To prevent the workpieces from transient out-of-plane buckling during local preset heating and welding, flattening forces P_1, P_2 are applied. P_1 is applied as close as practicable to the welding heat source and P_2 is applied as close as practicable to the area preheated to a higher temperature but in a third, cooled zone 7 defined by supports 8. The linear flattening forces P_1 uniformly distributed along straight lines parallel to the weld are normally selected in the range of 15-20 N/mm for thicknesses less than 4mm and 20-70N/mm for thicknesses above 4mm and the linear flattening forces P_2 are normally selected in the range of 10-15 N/mm for thicknesses less than 4mm and 15-50 N/mm for thicknesses above 4mm.

Figure 2 and 3 show the principle and relevant apparatus to carry out LSND welding for fillet weld and Tee type weld joints respectively. The cooling system 1 is so positioned to extract heat from the weld zone more effectively; three heaters 2 are applied for heating the side zones close to the weld in order to create a local preset heating temperature gradient or profile; the flattening forces P_1 and P_2 are loaded in the same way as described with reference to Fig. 1, to prevent the workpieces from transient out-of-plane buckling. The third cool zone is generated by contact with heat sinks defined by support bars 8.

Figure 4 shows the temperature (T) and stress (σ) distributions across the workpiece 6, before welding. As can be seen, the temperature profile comprises a first zone 9 which is cooled, a second, heated zone 10, and a third cooled zone 11. These three zones 9 - 11 are

duplicated on each side of the joint 4. The stretching effect due to σ_{max} of the tensile stress distribution in the weld zone induced by the temperature distribution (T) with a proper gradient across the workpiece 6 away from the weld zone 4 is also shown in Figure 4. To carry the LSND welding technique into execution, the local preset temperature distributions induced by the heating are determined mainly by three parameters shown in Fig. 4: T_{max}, T_o and H. The stretching effect due to σ_{max} becomes more effective as $(T_{max}-T_o)$ increases and H decreases. It is not essential, during heating and welding, to keep the value of σ_{pmax} at a level lower than the yield stress of the material at the temperature T_{max}. According to the mechanical and thermophysical properties of the material to be welded, as well as the specific characteristics of the structure itself, these main parameters, T_{max},T_o and H are selected by use of experimental measurements in combination with theoretical analyses of the thermal elastic-plastic strain-stress cycles with reference to the specific welding conditions. The value of $(T_{max}-T_o)$ is normally in the ranges of 80-200°C for aluminium alloys, 120-250°C for stainless steels, 250-350°C for titanium alloys. The values of H for different cases can be selected in the range of 40-120mm. For example, for stainless steel of thickness 1.6mm, H and G can be selected as: H = 55mm and G = 85mm, where G is the distance to the point of application of P_2 from the centre of the weld zone. In general, G=(1.5-2.0)H.

Figures 5 and 6 are, respectively, schematic views showing the flattening conditions with conventional "one-point" loading and the new "two-point" loading, each Figure illustrates the sheet in side elevation and plan. In the case of conventional one-point loading by P_1 as shown in Fig. 5, transient out-of-plane buckling

distortions always take place under compressive stresses in the thin-walled structural elements, caused by the combined effects of local preset heating temperature distribution and the welding temperature distribution. Once transient buckling occurs the potential energy induced by the stretching stress distribution and accumulated in the structural elements before buckling, is released and reduced to a minimum, and the value of σ_{max} (see Fig. 4) reduces suddenly; therefore the stretching effect is no longer in existence, and the low stress and non-distortion welding result cannot be achieved even if there is still a local preset heating temperature distribution in the workpiece to be welded. The structural elements can be kept free from any transient out-of-plane buckling if the flattening forces P_2 are additionally applied to the workpieces (see Fig. 6).

According to theory of plates and shells, the above mentioned condition can be described in more detail as follows. The critical compressive stress σ_{cr} at which the buckling occurs can be explained to a first approximation by the familiar equations:

$$\sigma_{cr} = \frac{1}{\lambda^2} \cdot \left(\frac{E}{1-\gamma^2}\right)$$

$$\text{or } \sigma_{cr} = K\left(\frac{t}{b}\right)^2 \frac{E}{1-\gamma^2}$$

where:
- λ - flexibility,
- t - thickness of thin-walled structural element, e.g. plate,
- K - Coefficient which depends on ratio a/b, manner of support and manner of loading,
- a - longitudinal dimension of plate,
- b - transverse dimension of plate,
- E - elastic modulus

γ - Poisson's ratio.

Thus σ_{cr} is inversely proportional to the square of flexibility λ; the higher the value of λ, the lower will be the value of σ_{cr}. The flexibility is a dimensionless value determined by the geometrical properties: i.e. the length and the geometry of cross-section of the thin-walled elements in combination with the end support conditions. The condition shown in Fig. 5 is the case where the plate has more degrees of freedom, particularly in the area with compressive stresses. In the absence of any supporting or restraining forces in these particular areas, the higher flexibility of the plate results in a lower critical stress at which transient buckling occurs. With the new method, the additional flattening forces P_2 or restraining means are applied to the workpieces in areas with stresses (as shown in Fig. 6), and therefore the thin-walled elements, being effectively stiffened by the flattening forces P_2 or a supporting restraining means, have acquired a lower flexibility and a higher σ_{cr}; in this manner, the plate to be welded can be prevented from transient out-of-plane buckling under the internal thermal compressive stresses.

In the case of welding hardenable materials by use of LSND welding method, the local preset heating temperature distributions are schematically shown in Fig. 7, where T_1 is the temperature distribution necessary for controlling the welding stresses and distortions, and T_2 is a uniform temperature field providing preheating as well as post weld heating necessary for improvement of weldability of material to be welded. Obviously, if hardenable materials are subjected to welding by use of the LSND welding method, the required temperature gradient as well as preheating and post-heating are provided by both the cooling and heating systems. Simultaneously, controlling the welding stresses and

distortions can be achieved as well as preventing the weld joint from over-hardening and cracking.

A typical example of experimental results is shown in Figs. 8 and 9. Two LF6 aluminium alloy specimens of 500 x 200 x 1.5mm are butt welded. Curve 81 in Fig. 8 shows the distribution (along the Y-axis orthogonal to the joint) of residual compressive plastic strains ε_x^p in the weld zone in the case of conventional welding. Curve 82 shows the results obtained with the same conditions for the case of LSND welding. These experimental results indicate that by means of the LSND welding technique, the residual compressive plastic strains can be controlled at a level lower than the critical value, therefore the residual welding distortion due to buckling can never occur.

Distributions of residual stresses due to the above mentioned plastic strains ε_x^p are shown in Fig. 9. Curves 83 and 84 show the results of conventional welding and the LSND welding technique respectively. Thus, by means of the LSND technique the peak residual tensile stress in the weld can be controlled at a lower level. Residual stress measurements show that the buckling deflection of such specimens welded by conventional TIG welding reaches 14mm, but not any deflection appears in the case of LSND welding. Experiments show clearly that the low stress and non-distortion results can be provided by use of the LSND welding technique.

Under certain circumstances, it may also be useful to create a temperature distribution with a higher value of T_{max}, which is sufficient to cause an excess of local thermal stress σ_{pmax} over the value of the yield stress of the material at T_{max}. As a result, compressive plastic strains will occur in the area with T_{max}, which will radically alter the residual stresses magnitude and distribution. After welding with higher T_{max} the

distribution of residual stresses always assumes a complicated pattern. Figure 10 shows a typical pattern of residual stress distribution after welding with higher T_{max}. See Fig. 10, curve 19. It can be seen clearly that the residual stresses alternately interchange from tensile to compressive symmetrically to the centre line 4 of the weld. Two more zones with tensile residual stresses appear in areas where T_{max} causes thermal compressive plastic strains. The maximum value of tensile residual stress in the weld has been reduced rapidly.

The compressive residual stresses after LSND welding seem to be somewhat higher, in comparison with those after conventional welding (see Fig, 10, curve 18) but they are still much lower than the maximum value of tensile residual stress in the weld after conventional welding. Due to the tension effect of the tensile stresses (as a stiffening effect) between the compressively stressed strips, the compressive residual stresses in this case cannot cause buckling. The workpiece remains distortion-free and keeps its shape as flat as it was before welding. Fig. 11 compares the deflections "f" (Fig. 11A) of two conventionally welded stainless steel sheet pairs of 100 x 200 x 1.6mm (Fig. 11B) with two sheet pairs of the same dimensions welded using the new technique (Fig. 11C). It can be seen clearly that deflections were substantially prevented in case of LSND welding while the deflections reach 30-40mm in case of conventional welding.

Obviously, with the new welding technique distortion-free results can be achieved not only by means of heating with T_{max} to keep the value of σ_{pmax} lower than the yield stress but also by applying heating with T_{max} exceeding a certain value which causes compressive plastic strain. With this specific pattern of residual

stress distribution, the compressive residual stresses can not cause buckling.

The LSND welding process may be carried out with many known welding heat sources, e.g. gas flames, electric arcs, high energy density beams (laser beam or electron beam etc.). The welding torch 3 could be mounted on a moving mechanism such as a carriage, or an overhanging beam, or a frame. The cooling system may comprise a cooling insert backup bar 12 (Figure 12) positioned under the weld coupled with devices (not shown) for supplying the heat sink cooling medium such as water through a pipe 13. The heating system comprises heating elements 14 (applicable: electrical resistance elements, induction heating infrared elements, gas flames etc) and heat insulation elements 15. The required temperature distributions in the workpieces are created by regulation of both the cooling and heating system. The loading system consists of pneumatic devices (alternatively, hydraulic or mechanical means), a hinged double finger clamping loading mechanism 16 and firm backup supporting bars illustrated schematically at 17. A microcomputer (or other control circuits), electronic circuits and units, (all omitted for clarity) provide the required temperature distributions and appropriate flattening forces on workpieces. Temperatures may be checked at certain points on the workpieces if necessary.

By use of LSND welding apparatus, the welding of longitudinal butt joints of plane parts or cylindrical, conical shells is applicable to all weldable materials, including ferrous as well as non-ferrous metals. The thickness of thin walled structural elements to be welded by LSND welding can be defined as mentioned above by theory of plates and shells. Significant distortion-free results can be achieved expecially with elements of thickness less than 4mm. Undoubtedly, in this manner,

welding of thin-walled components with thicknesses above 4mm is also available.

The facility is operated as follows:-

1. Positioning workpieces to be welded into the apparatus.

2. Selecting the required local preset heating temperature distribution according to the characteristics of materials used and the structure itself.

3. Creating the stretching effect due to temperature gradient by regulating the cooling, heating and loading systems.

4. Welding the workpiece while maintaining the established temperature distribution during welding.

For given characteristics of materials and structure, heating to an optimised temperature distribution and maintaining it during welding can be imposed automatically through a control block stored in the control board for selecting the local preset heating temperature distributions. Therefore, by using this apparatus, all the parameters for welding and controlling procedures can be regulated properly and easily. This technique has proved successful, efficient and even more cost saving.

The structural details of this apparatus for low stress and non-distortion welding of longitudinal butt joints in thin-walled structural elements (plane sheets, cylindrical or conical shells) can be seen from the cross-sectional views shown in Figs. 12 and 13. They are the cooling backup insert or bar 12, heating elements 14, insulation 15 welding heat source 3, workpieces 5, 6, hinged double finger clamping mechanism 16, and backup supporting bars 17. The welding process can be carried out manually, semi-automatically or fully-automatically. Besides copper, other materials could also be used for the cooling backup insert; heat-sinking liquid mediums or

other materials may be used to achieve the cooling effect.

The heating elements 14 may consist of several heaters positioned in parallel in both side cavities of respective support bars. Thus, the temperature distributions can be regulated by controlling output powers on each heater without repositioning of any single one. The loading system, comprising hinged double finger clamping mechanism 16, cooling backup insert 12 and supporting bars 17, prevents the workpieces from transient buckling during local preset heating and welding. One of the supporting backup bars with cooling backup insert 12 is located in the centre exactly under the weld; the other two supporting bars 17 are located symmetrically on both sides of the central backup bar; the cavities between the central and side bars contain the heating element and heat insulation materials.

Flattening forces on the workpieces on both sides of the weld are provided by two opposing rows of hinged double finger clamping, holding the workpieces firmly against both the central backup insert 12 and the side supporting bars. These three backup and supporting bars could be either machined as one integrated body or separately manufactured and assembled. The upperside surfaces of the insert and supporting bars should be machined to coincide with the proper shape of the structural elements to be welded. Thus, each finger clamps a part of the workpiece adjacent the weld and in the third zone 11 of the temperature profile adjacent the second zone.

Figures 14 - 16 illustate schematically part of apparatus for continuously welding a joint between a pair of planar workpieces 30, 31, the joint being indicated at 32. The apparatus includes a lower support member 33 and an upper support member 34. The upper support member 34

carries a welding torch 35 together with a pair of roller support members 36, 37 having a generally trapezoidal cross-section and each carrying on opposed elongate faces a set of rollers 38.

The lower support 33 also carries a pair of support members 39, 40 similar to the members 36, 37 with which they are aligned, each support member 39, 40 carrying a respective plurality of rollers 41.

An elongate backing bar 42 is supported under the welding torch 35 via a compression spring 43 mounted in the support 33 and is urged towards the workpieces 30, 31 in alignment with the joint 32.

As can be seen more clearly in Figure 15, the backing bar 42 is supported by a number of rods 44 spaced along the support 33 and extending into respective bores in the support 33. The lower end of each rod 44 has a laterally extending flange 45 positioned within a counterbore 46 so that a certain degree of vertical movement of the backing bar 42 is permitted under the influence of the spring 43.

The required temperature profile across the weld joint 32 is created upstream of the welding position (47, Figure 16) at which the welding torch 35 is positioned. At alternating positions along the path of the workpieces 30, 31 towards the welding position 47 and each side of the joint, the workpieces are cooled and heated at respective laterally spaced positions relative to the joint. Each cooling stage has a pair of conduits 48, 49 which extend through bores in the support 33 and between adjacent pairs of the rollers 41 to cause coolant, such as liquid CO_2 or water, to impinge on the adjacent workpiece so as to generate the required heat sink or cooled zones 50, 51. Each heating stage comprises a conduit 52 extending through apertures in the support 33 for conducting fuel, such as natural gas, through the

supports 39, 40 which is burned adjacent the workpieces and raises the temperature of the workpieces in the adjacent zone 53.

In operation, the two workpieces 30, 31 are tack welded together to define the joint 32 and the temporally joined workpieces are then presented to the junction between the rollers 38, 41. The space between these rollers is chosen so that the workpieces are restrained from out-of-plane movement but are not nipped so that they can move between the rollers. The workpieces 30, 31 are then moved through the rollers 38, 41 towards the welding position 47 during which they pass in series over the cooling and heating stages described above. In this way, the required temperature profile across the joint is created within the workpieces by the time the welding positon 47 is reached. Welding then takes place with the rollers 38, 41 preventing transient out-of-plane buckling movement.

The applications of the invention described so far have been concerned primarily with the butt welding of plane members. The invention is also applicable, however, to the welding of tubular members butted together and in particular cylindrical members and has particular application in the welding of cylinders where access to the space within the cylinders is not available.

In some cases, LSND welding for circumferential welds is aimed at elimination of residual stress versus the reduction of welding distortions and it is desirable to avoid the post welding heat treatment for stress relief.

An example of a stationary welding system for welding a pair of cylinders together is illustrated in Figure 17. As can be seen in Figure 17, two cylinders 60, 61 are butted together to define a joint 62. The

zones 63, 64 on each side of the joint 62 are cooled by means of cooling fluid such as water passing through respective permeable hoses 65, 66 wrapped around the cylinders. Axially outwardly of these zones, two heated zones 67, 68 are generated by means of heating elements 69, 70. Axially outwardly of the heated zones, a pair of permeable hoses 71, 72 are provided to carry further cooling fluid around the cylinders so as to generate outer, cool zones 73, 74.

Figure 17 illustrates graphically the preset temperature profile and stress profile of the cylinders 60, 61 in use.

It will be noted that no additional restraining means is provided equivalent to the forces P_1, P_2 of earlier examples. The reason for this is that the cylinders themselves have an adequate stiffness in combination with the special form of temperature profile to prevent buckling taking place.

Figures 18 and 19 illustrate schematically the welding of cylindrical workpieces using a moving LSND welding apparatus. In this case, a carriage 75 carrying a welding torch 76 is mounted on the cylinders 60, 61. The carriage is mounted on a number of rollers 77 which run along the surface of the cylinders 60, 61. In the preferred arrangement, the carriage 75 is mounted within a stationary housing and the cylinders 60, 61 are rotated relative to the housing and the carriage. It would also be possible, however, for the carriage 75 to be rotated around the cylinders 60, 61 which are themselves held stationary.

Mounted on the carriage 75 are a series of cooling jet supply conduits 78, 79 with corresponding series of heating fluid supply conduits 80 positioned between them. The series of cooling jets and heating flames impinge on

the workpieces and cause the generation of the required temperature profile.

CLAIMS

1. A method of welding a weld zone defined by one or more workpieces, the method comprising creating a temperature profile across an area including the weld zone, the temperature profile comprising in sequence a first zone including the weld zone, a second zone adjacent the first zone and having a temperature higher than the first zone, and a third zone adjacent the second zone and having temperature lower than the second zone; and performing the weld operation on the weld zone while the temperature profile exists and while restraining buckling movement of the workpiece or workpieces.

2. A method according to claim 1, wherein the weld zone has an elongate form.

3. A method of continuously welding an elongate weld zone defined by one or more workpieces, the method comprising creating a temperature profile across an area including the weld zone, the temperature profile comprising in sequence a first zone including part of the weld zone, a second zone adjacent the first zone and having a temperature higher than the first zone, and a third zone adjacent the second zone and having a temperature lower than the second zone, the temperature profile being created at a position upstream of a welding position; causing relative movement between the said part of the weld zone and the welding position; and performing a weld operation on the said part of the weld zone at the welding position while the temperature profile exists across the part of the weld zone and while restraining buckling movement of the workpiece or workpieces.

4. A method according to claim 1, wherein the first and third zones have substantially the same temperature.

5. A method according to claim 3, wherein the first and third zones have substantially the same temperature.

6. A method according to claim 1, wherein the first, second and third zones of the temperature profile are duplicated on each side of the weld zone.

7. A method according to claim 3, wherein the first, second and third zones of the temperature profile are duplicated on each side of the weld zone.

8. A method according to claim 1 for welding a workpiece or workpieces of hardenable material, wherein the temperature profile is superposed on a substantially uniform preheating temperature.

9. A method according to claim 3 for welding a workpiece or workpieces of hardenable material, wherein the temperature profile is superposed on a substantially uniform preheating temperature.

10. A method according to claim 1, wherein the maximum temperature within the second zone is selected so that additional thermal compressive plastic strains can be created in that zone.

11. A method according to claim 3, wherein the maximum temperature within the second zone is selected so that additional thermal compressive plastic strains can be created in that zone.

12. A method according to claim 1, wherein the restraining step includes the step of applying a force to the workpiece or workpieces adjacent the weld zone.

13. A method according to claim 3, wherein the restraining step includes the step of applying a force to the workpiece or workpieces adjacent the weld zone.

14. A method according to claim 1, wherein the restraining step includes a preliminary step of carrying out a first welding pass along the weld zone or applying a plurality of tack welds in the weld zone.

15. A method according to claim 3, wherein the restraining step includes a preliminary step of carrying

out a first welding pass along the weld zone or applying a plurality of tack welds in the weld zone.

16. A method according to claim 1, wherein the weld zone is defined by a pair of butted tubular workpieces, a fillet joint or a Tee joint.

17. A method according to claim 3 wherein the weld zone is defined by a pair of butted tubular workpieces, a fillet joint or a Tee joint.

18. A method according to claim 1 wherein the restraining step is performed by restraining means positioned at the third zone.

19. A method according to claim 3, wherein the restraining step is performed by restraining means positioned at the third zone.

20. A method according to claim 18, wherein the restraining means applies flattening forces at the third zone.

21. A method according to claim 19, wherein the restraining means applies flattening forces at the third zone.

22. A method according to claim 18, wherein the restraining means are at a distance G from the centre of the weld zone, where G is in the range 1.5H to 2.0H and where H is the distance from the centre of the weld zone to the position of maximum temperature within the second zone of the temperature profile.

23. A method according to claim 19, wherein the restraining means are at a distance G from the centre of the weld zone, where G is in the range 1.5H to 2.0H and where H is the distance from the centre of the weld zone to the position of maximum temperature within the second zone of the temperature profile.

24. A method according to claim 1, wherein the thickness of the or each workpiece is less than or equal to 4 mm.

25. A method according to claim 3, wherein the thickness of the or each workpiece is less than or equal to 4 mm.

26. Apparatus for welding a weld zone defined by one or more workpieces, the apparatus comprising temperature profile generating means for creating a temperature profile across an area of the workpiece or workpieces including the weld zone, the temperature profile comprising in sequence a first zone within which the weld zone is positioned in use, a second zone adjacent the first zone and having a temperature higher than the first zone, and a third zone adjacent the second zone and having a temperature lower than the second zone; and welding means for performing a weld operation on the weld zone while the temperature profile exists across the area, the arrangement being such that during a weld operation buckling movement of the workpiece or workpieces is restrained.

27. Apparatus according to claim 26, wherein the temperature profile generating means is positioned upstream of the welding means whereby the weld zone is moved to the welding means after the profile has been created.

28. Apparatus according to claim 26, the apparatus further comprising restraining means positioned adjacent the third zone of the temperature profile for restraining buckling movement of the workpiece or workpieces during a weld operation.

29. Apparatus according to claim 28, wherein the restraining means includes first means positioned adjacent to but spaced from the workpiece or workpieces in use to restrain movement of the workpiece or workpieces towards the restraining means.

30. Apparatus according to claim 28, wherein the restraining means includes second means for applying

holding forces on the workpiece or workpieces adjacent the weld zone.

31. Apparatus according to claim 28, wherein the restraining means comprises at least one load member having a pair of fingers, one of which contacts a workpiece in the first zone and the other of which restrains the workpiece in the third zone.

32. Apparatus according to claim 26, wherein the temperature profile generating means comprises first cooling means for cooling the first zone, heating means for maintaining the second zone at a temperature higher than the first zone, and second cooling means for cooling the third zone.

33. Apparatus according to claim 32, the apparatus further comprising restraining means positioned adjacent the third zone of the temperature profile for restraining buckling movement of the workpiece or workpieces during a weld operation.

34. Apparatus according to claim 32, wherein the first cooling means comprises means for spraying cooling fluid onto the workpiece or workpieces within the first zone and the second cooling means comprising means for spraying cooling fluid onto the workpiece within the third zone.

Fig.1.

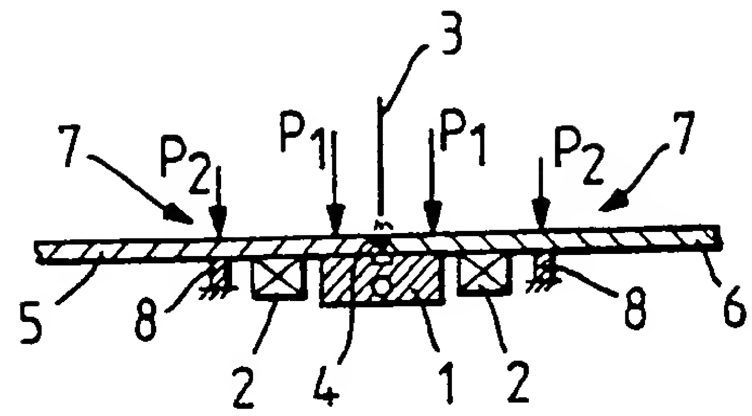


Fig.2.

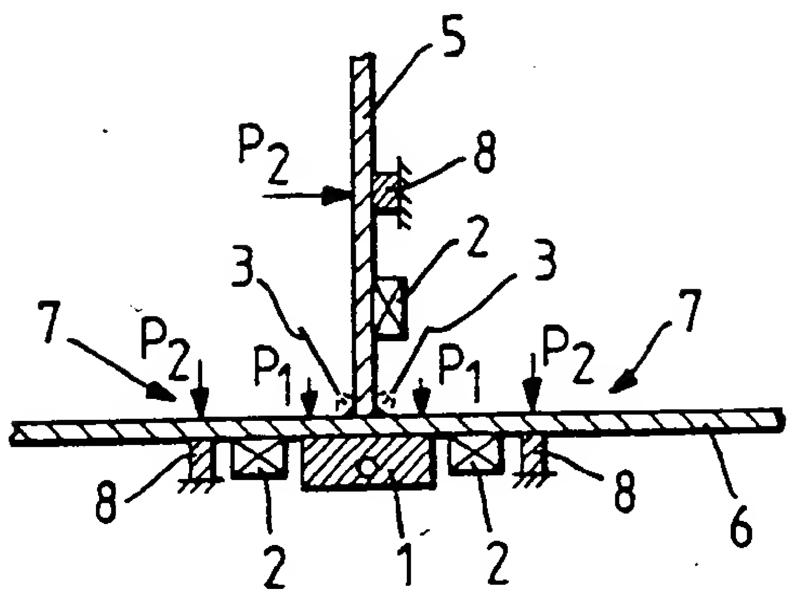


Fig.3.

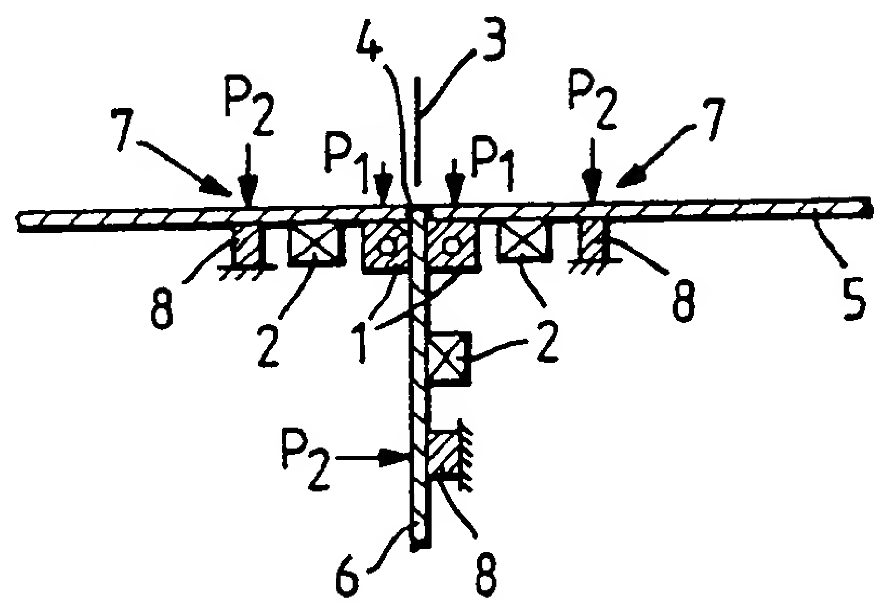


Fig.4.

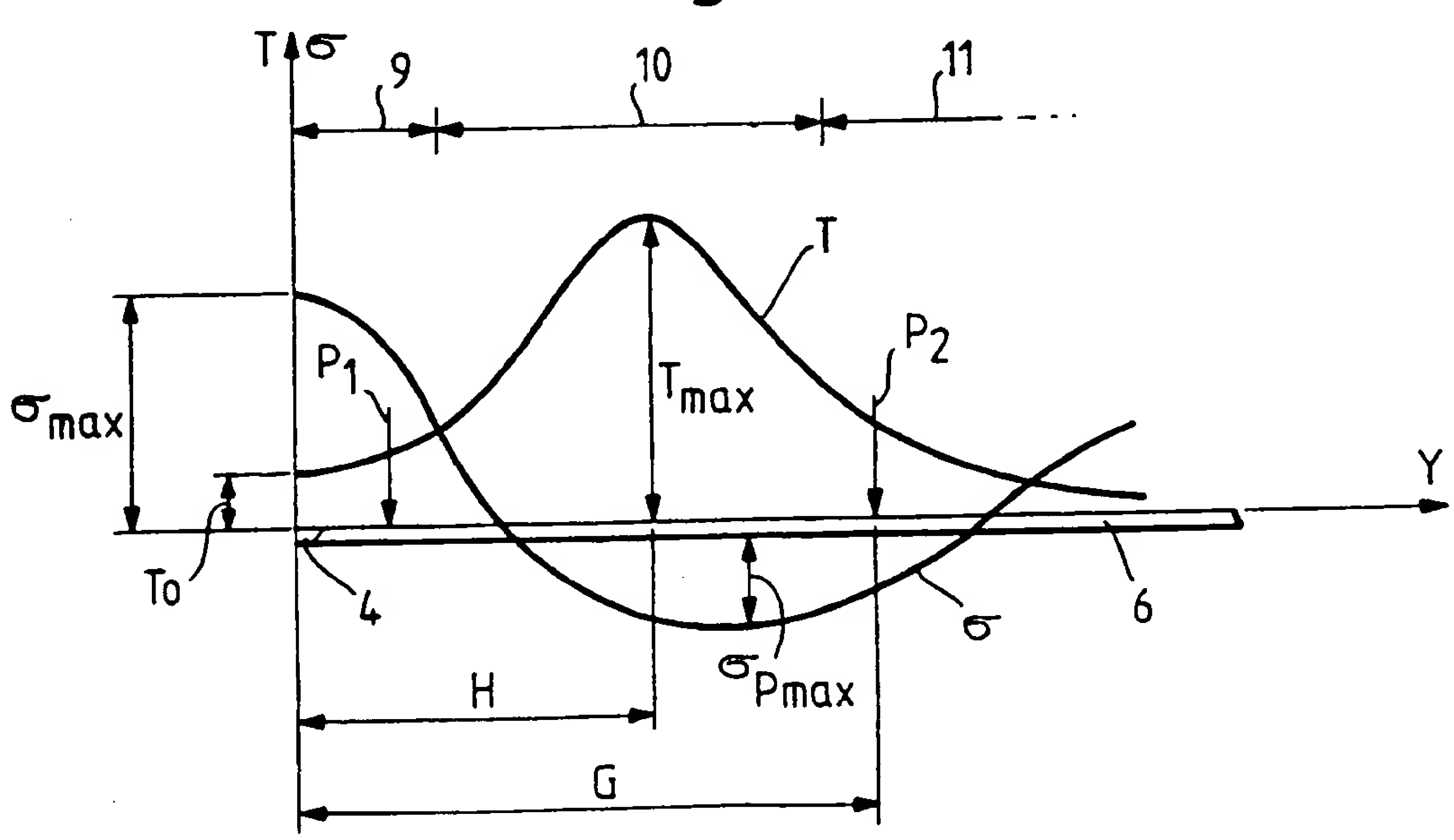


Fig.5.

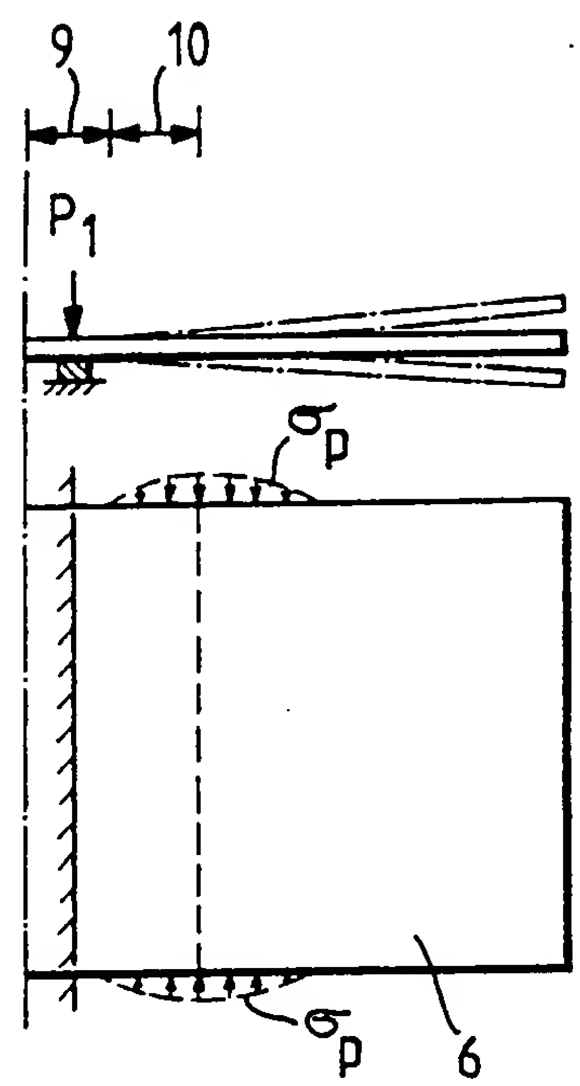


Fig.6.

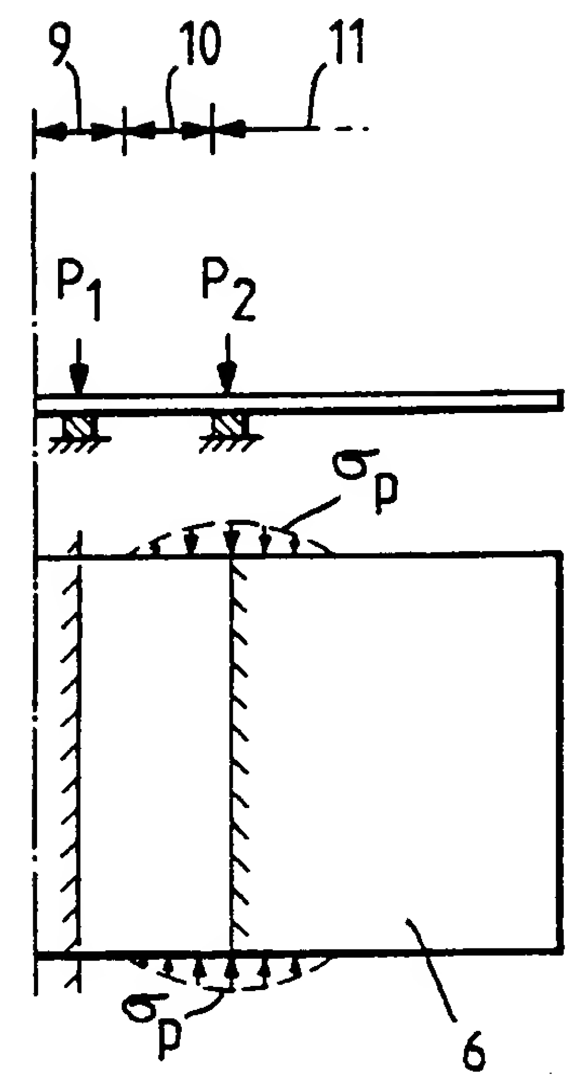


Fig.7.

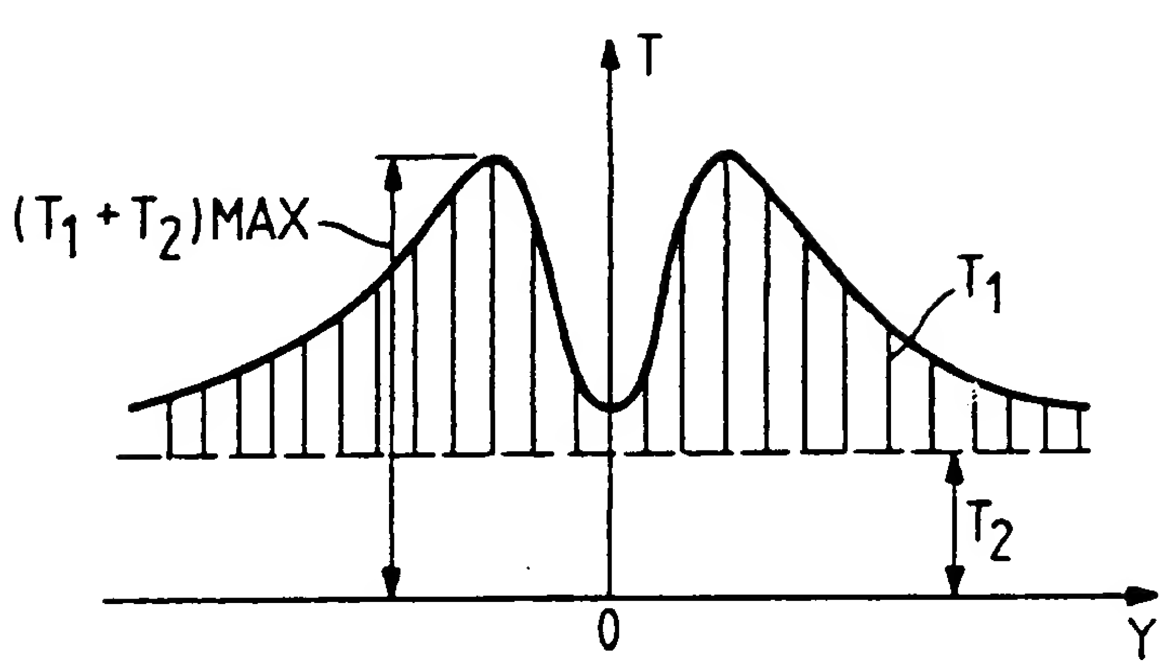


Fig.8.

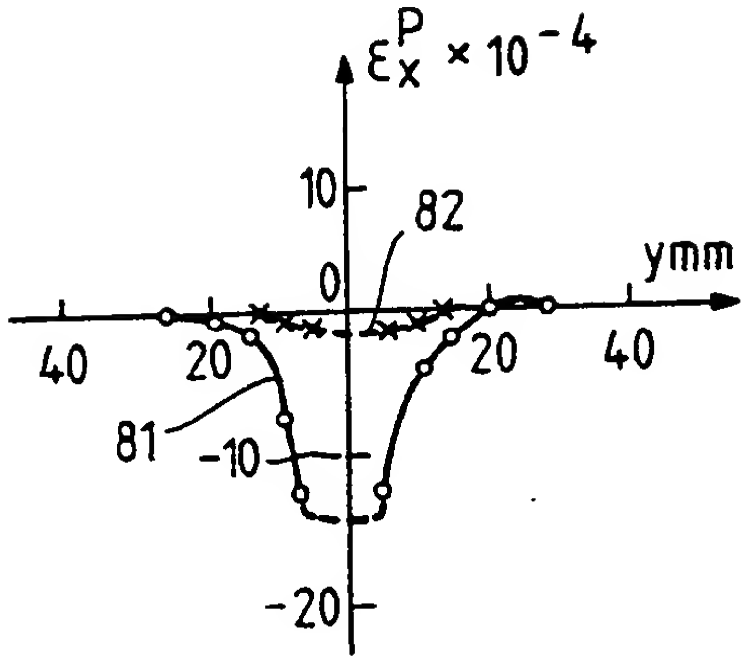


Fig.9.

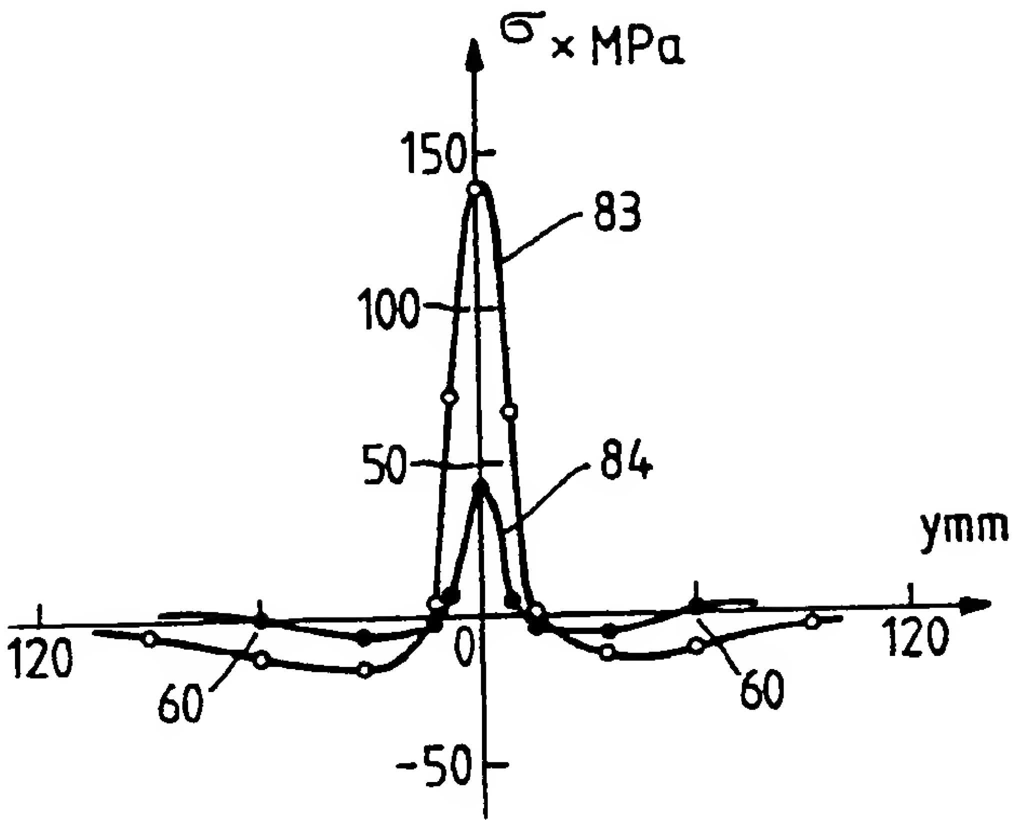


Fig.12.

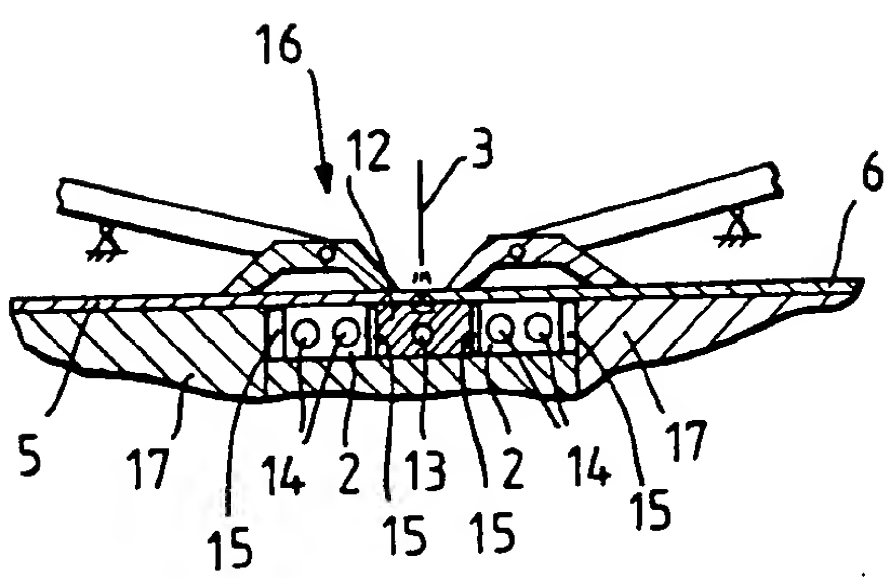


Fig.13.

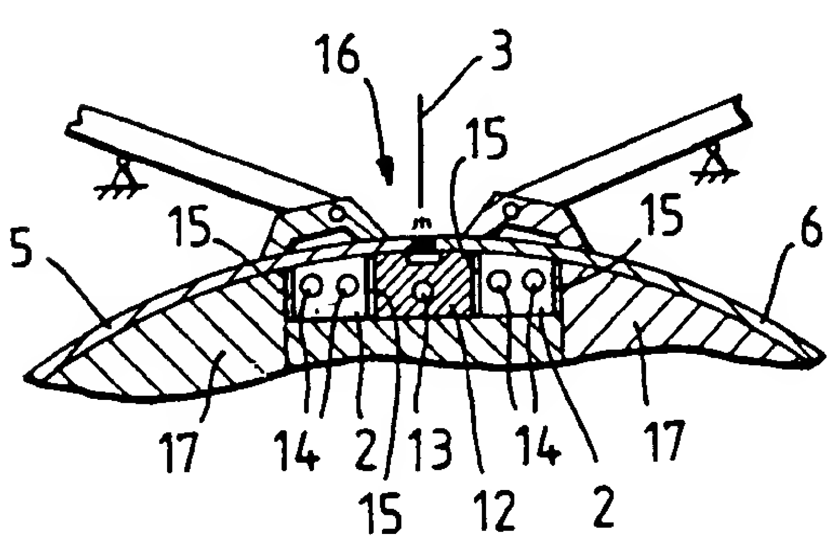


Fig. 10.

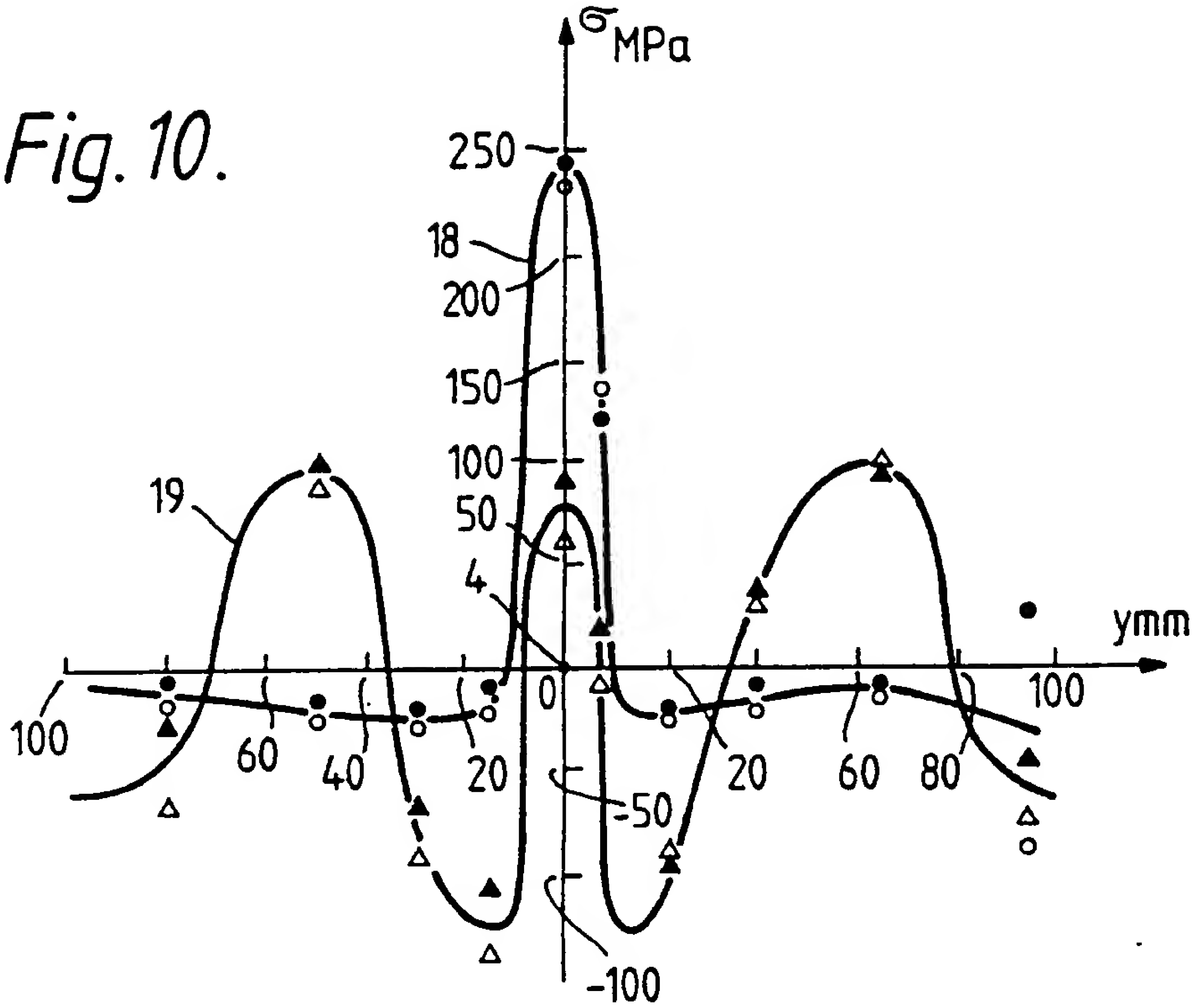


Fig. 11A.

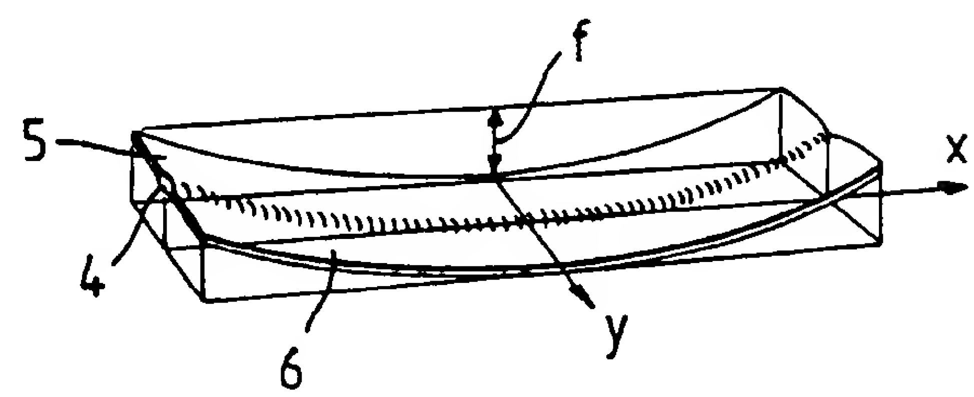


Fig. 11B.

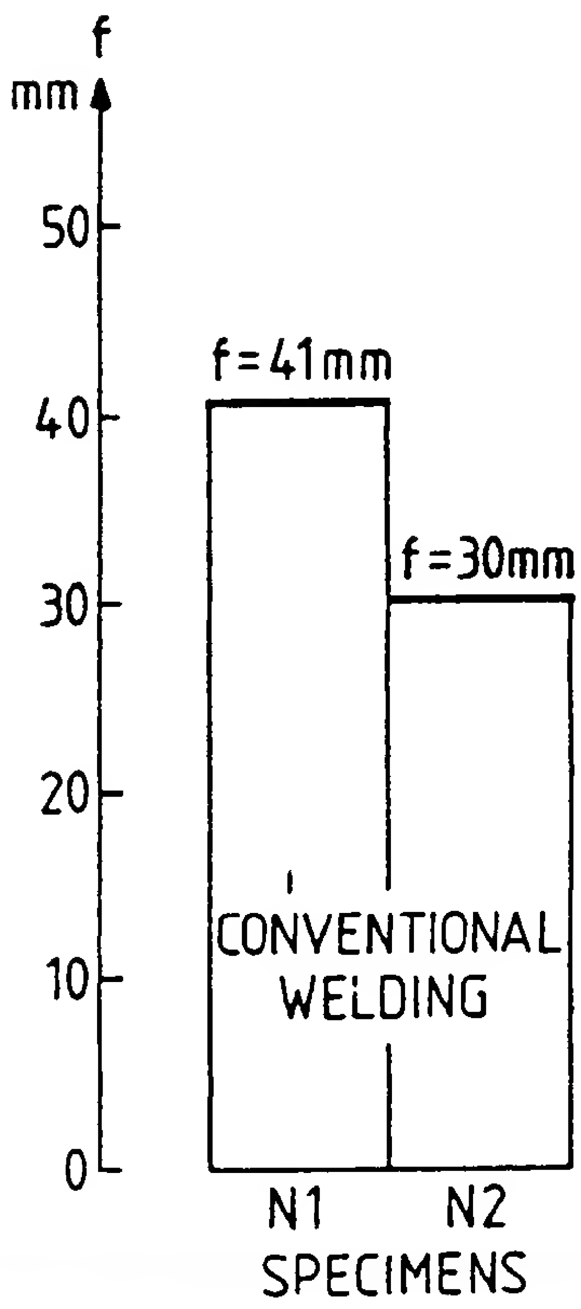


Fig. 11C.

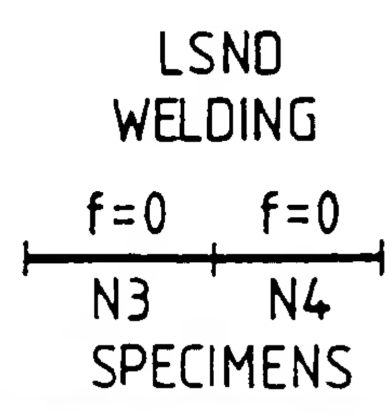


Fig. 14.

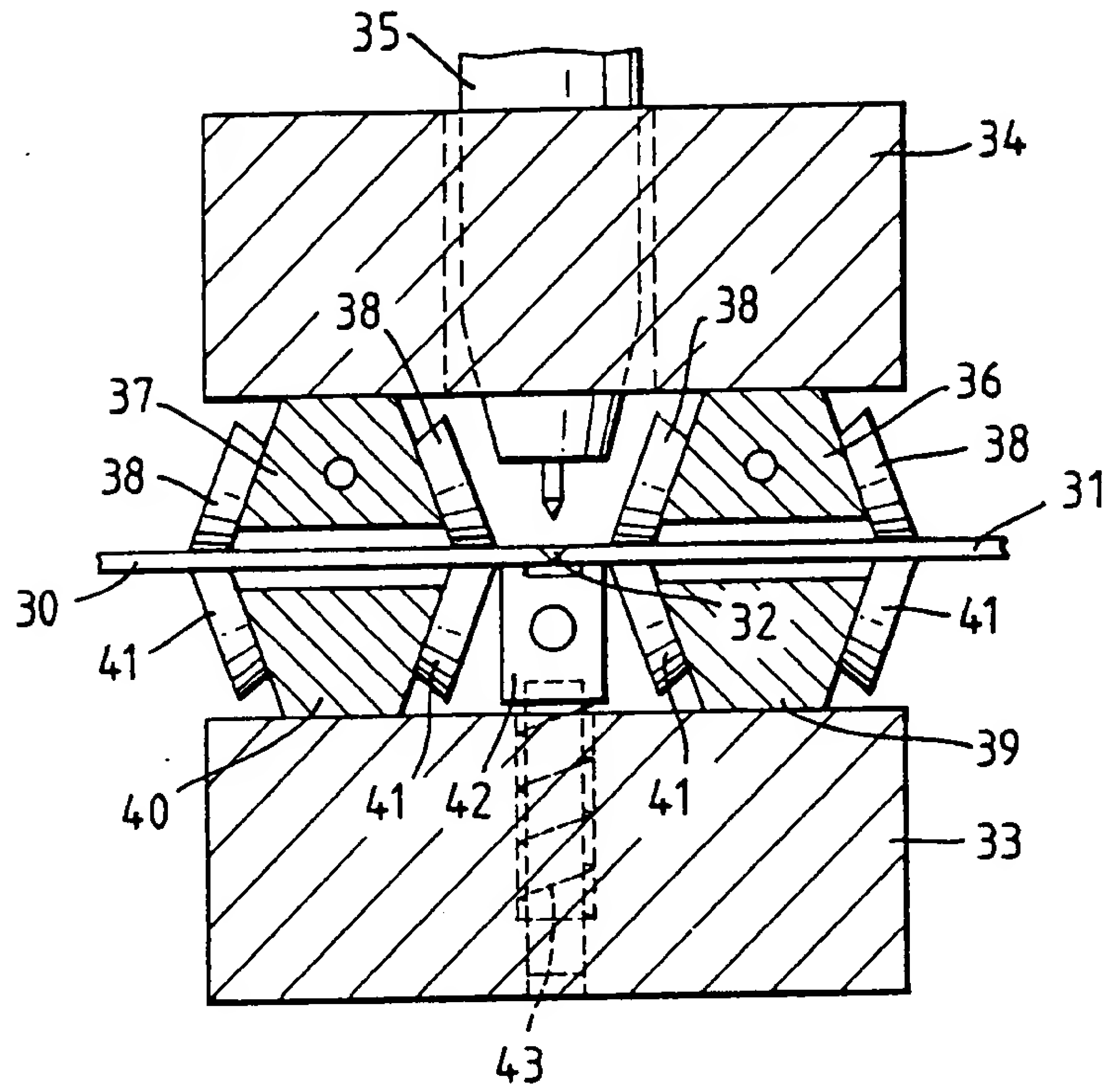


Fig. 15.

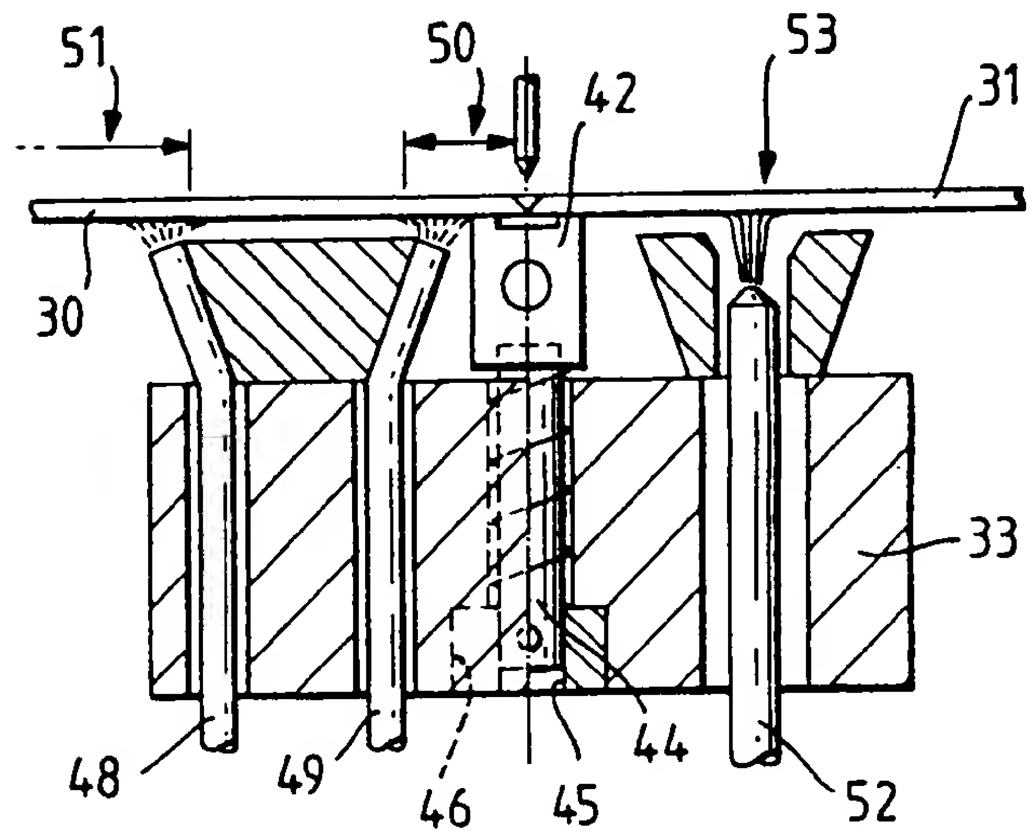
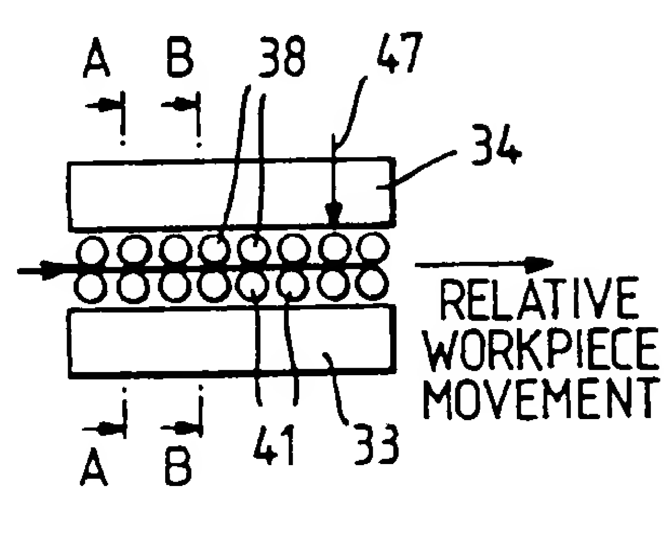


Fig. 16.



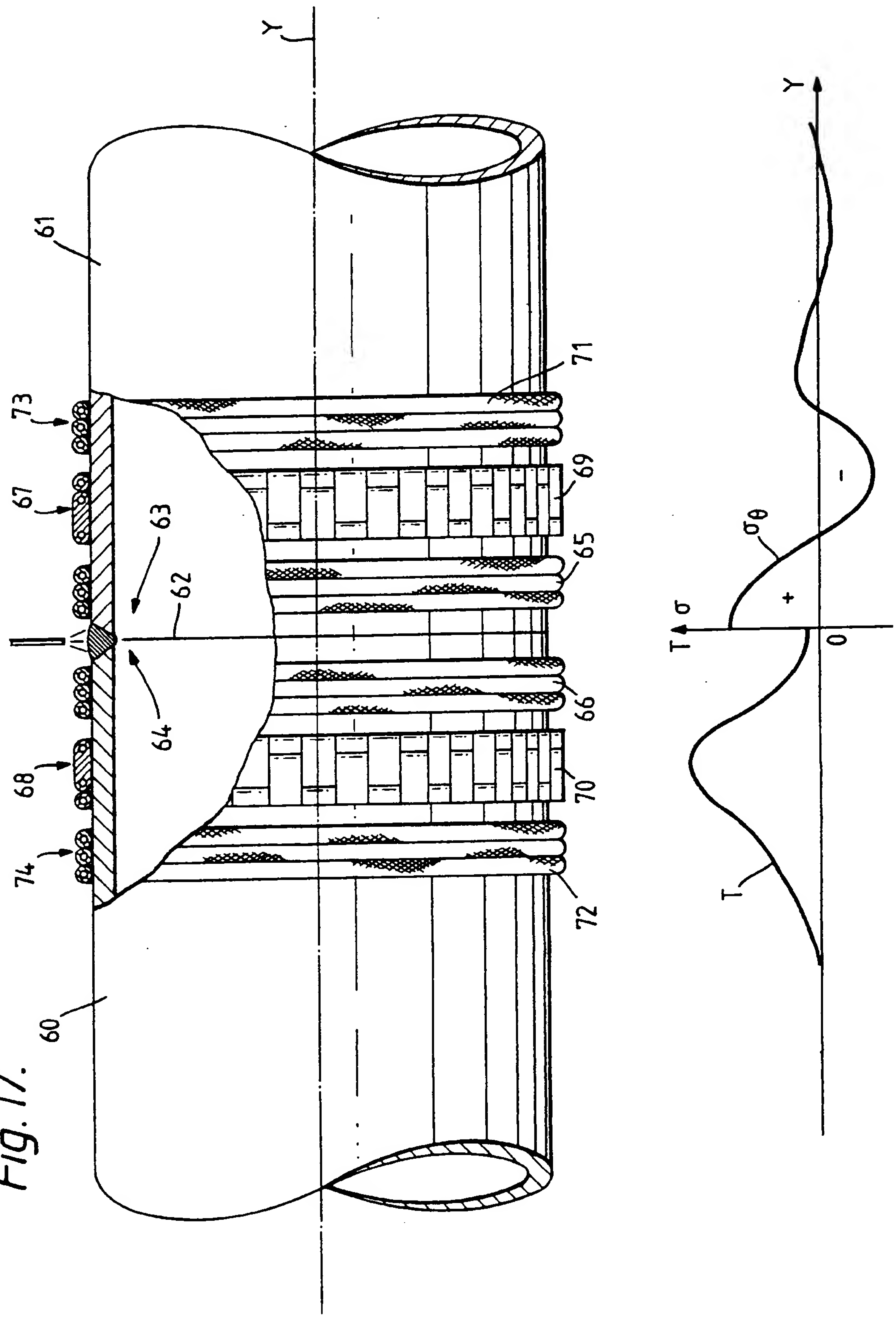


Fig. 17.

Fig. 18.

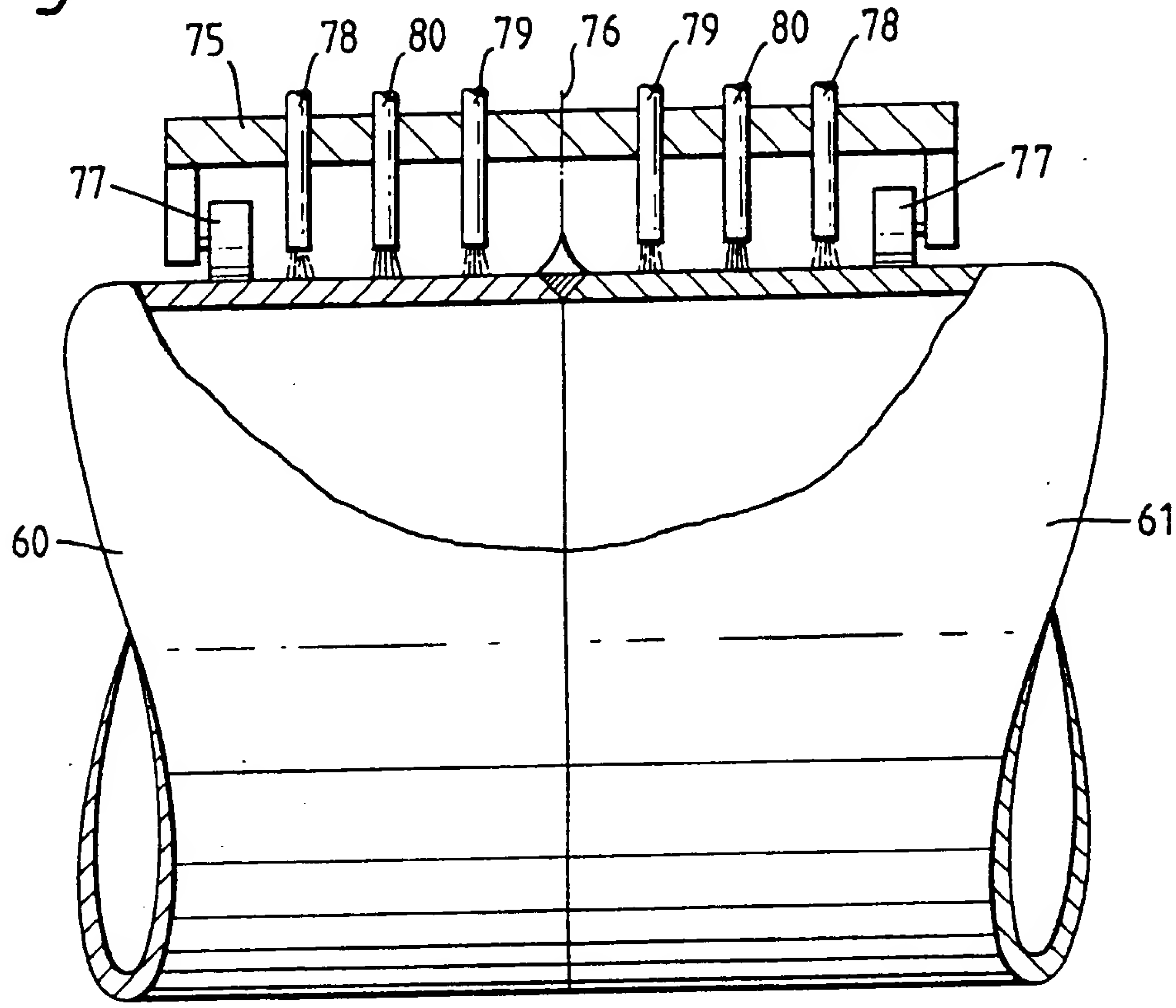

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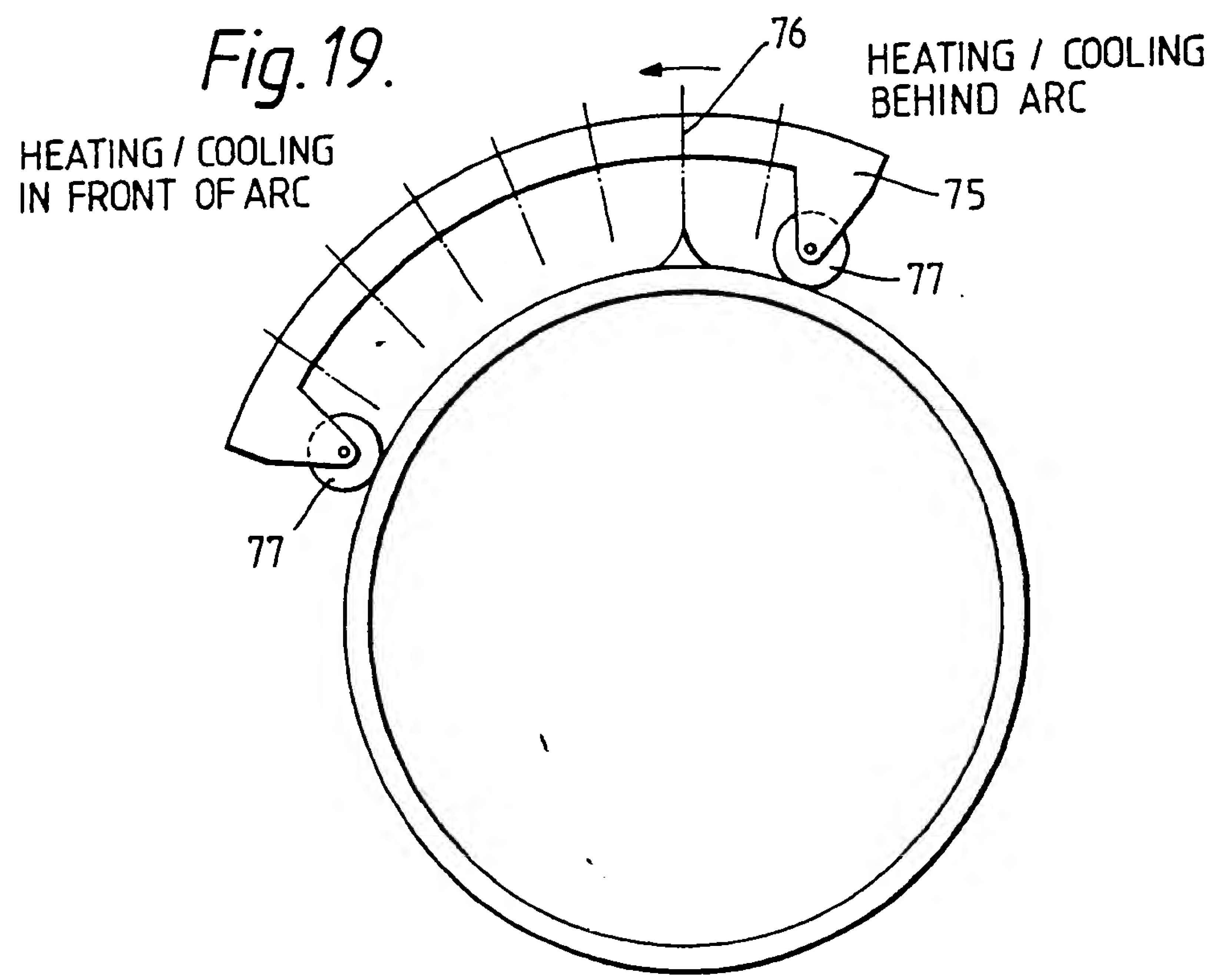
Fig. 19.


76
HEATING / COOLING
BEHIND ARC
HEATING / COOLING
IN FRONT OF ARC
75
77
77

INTERNATIONAL SEARCH REPORT

International Application No PCT/GB 88/00136

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) [6]

According to International Patent Classification (IPC) or to both National Classification and IPC

IPC^4: B 23 K 31/02; F 16 L 13/06; B 23 K 9/235; C 21 D 9/50

II. FIELDS SEARCHED

Minimum Documentation Searched [7]

Classification System	Classification Symbols
IPC^4	B 23 K; F 16 L; C 21 D

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched [8]

III. DOCUMENTS CONSIDERED TO BE RELEVANT [9]

Category *	Citation of Document, [11] with indication, where appropriate, of the relevant passages [12]	Relevant to Claim No. [13]
Y	GB, A, 846597 (DEUTSCHE EDELSTAHL WERKE AKTIENGESELLSCHAFT) 31 August 1960 see page 2, lines 66-95; figures 1,2a --	1-3,6,7,12, 13,16,17,26 27
Y	FR, A, 2202957 (VIDA-WELD, LTD) 10 May 1974	1-3,6,7,12, 13,16,17,26 27
A	--	20,21,32,34
A	Welding Production, vol. 32, no. 10, October 1985 (Cambridge, GB) V.M. Sagalevich et al.: "Preventing welding strains caused by circular joints in spherical shells", pages 38,39; see the whole document --	1,3,8-13,16 -21,26,28- 30,32,33
A	US, A, 3610863 (N.F. DOUBLET) 5 October 1971 see column 4, line 63 - column 6, line 10; figure 8 --	1-3,12,13, 16,17,26,28 -33 ./.

* Special categories of cited documents: [10]

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

IV. CERTIFICATION

Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report
31st May 1988	21 JUL 1988
International Searching Authority	**Signature of Authorized Officer**
EUROPEAN PATENT OFFICE	P.C.G. VAN DER PUTTEN

III. DOCUMENTS CONSIDERED TO BE RELEVANT (CONTINUED FROM THE SECOND SHEET)		
Category *	Citation of Document, with indication, where appropriate, of the relevant passages	Relevant to Claim No
A	FR, A, 2504042 (SOCIETE ANONYME DE FABRICATION INDUSTRIELLE ET AERONAUTIQUE DE LANNE (SAFIAL)) 22 October 1982 see page 10, line 32 - page 11, line 9; figures 7,8	1-3,12,13,16, 17,26,28-33
A	Automatic Welding, volume 30, no. 3, 1977, Ya.L. Burak et al.: "Controlling the longitudinal plastic shrinkage of metal during welding", pages 21-24, see page 21; page 23, column 2; figures 1,2, & Avt. Svarka, 1977, no. 3, pp. 27-29, cited in the application	1-3,12,13,16 17,26,28-33
A	Welding International, vol. 1, no. 8, 1987 (Abington, Cambridge, GB) L. Zhiwen: "End cracking during one-sided submerged-arc welding", pages 774-779, see pages 774, 775; figure 3 (selected from Trans China Welding Institution 1986 7(3)	14,15
A	Welding Journal, vol. 66, no. 6, June 1987, Welding Workbook, Datasheet no. 88a, copyright 1975 by the American Welding Society (Florida, FL, US) "How to prepare welds in piping and tubing for localized heat treatment", pages 57-58, see the whole document	16,17
A	Automatic Welding, volume 32, 1979, Ya.L. Burak et al.: "Selection of the optimum fields for preheating plates before welding", pages 5-9, & Avt. Svarka, 1979, no. 5, pp. 15-19, cited in the application	
A	SU, A, 1066765 (ASTAKHOV L.S. et al.) 15 February 1984 cited in the application	

ANNEX TO THE INTERNATIONAL SEARCH REPORT ON INTERNATIONAL PATENT APPLICATION NO. GB 8800136

SA 20941

This annex lists the patent family members relating to the patent documents cited in the above-mentioned international search report.
The members are as contained in the European Patent Office EDP file on 30/06/88
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Patent document cited in search report	Publication date	Patent family member(s)	Publication date
GB-A- 846597		None	
FR-A- 2202957	10-05-74	BE-A- 805206	16-01-74
		GB-A- 1391018	16-04-75
		AU-A- 6035473	20-03-75
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US-A- 3610863	05-10-71	NL-A- 6917510	22-05-70
		NL-A- 6917509	22-05-70
		DE-A,B,C 1957834	30-07-70
		FR-A- 1599054	15-07-70
		DE-A,B 1957835	08-10-70
		BE-A- 741938	19-05-70
FR-A- 2504042	22-10-82	None	
SU-A- 1066765		None	

EPO FORM P0479

For more details about this annex : see Official Journal of the European Patent Office, No. 12/82